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MEASUREMENT OF CASTING PARAMETERS IN ZnAlCu$_3$ MOLDS CREATED BY ADDITIVE TECHNOLOGY

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Preliminary Note – Prethodno priopćenje

This paper examines the parameters of casting ZnAl$_4$Cu$_3$ alloy (volume, castability, density and occupancy of the mold) in mold made additive technology. Molds made by additive technology are: cheaper in production of a small number of castings, geometrically more accurate and faster made. From obtained results of this paper it is clearly seen that printed mold must be protected with thermal coating because liquid adhesive of powder otherwise evaporates during casting and creates additional moisture in the mold, as it was noted.

Key words: casting, ZnAlCu$_3$, additive technology, zirconium dioxide coating

INTRODUCTION

The aim of new structural solutions is the reduction of mass with at the same time maintaining the solidity of the components. The tendency in casting technology is to reduce the number of steps towards the finished product and to increase the geometric accuracy. A mold must be made out of a material that is multiply more resistant in temperature in comparison to cast alloy [1]. Since 2009, rapid prototyping, rapid manufacturing and rapid tooling procedures have been reduced to a term additive technologies [2, 3]. Previous research of casting in full disposable mold where the castability of AlSi12 was examined in regards to density of polystyrene test strips [4] as a standard castability test , gave rise to the necessity of polymer mold development. The high cost of foundry experiments and trials under daily production conditions makes it appropriate

to use all available methods to simulate and to improve the casting design by small modifications [5] and protection with thermal coating [6]. The paper examines the casting of the ZnAl$_4$CU$_3$ alloy in molds made by the use of additive technologies of 3D Printing and Fused Deposition Modelling (FDM). The goal is to establish repeatability of casting in order to obtain at least 4 castings in one mold. In this paper, two materials were used in mold production: polylactic acid and silicate plaster powder. Polylactic acid material has a heat deflection according to ISO 75 at 65 °C , which given the temperature of casting ZnAl4Cu$_3$ alloy in the range of 400 - 580 ° C is quite small. Silicate plaster powder has no heat deflection data, but while pre-testing the material in a full disposable mold during the casting of AlSi12 alloy at 780 °C, no contraction of test strips was detected.

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EXPERIMETAL PROCEDURES

Initial testing will be carried out on molds produced by Fused Deposition Modeling. Material for the mold production is polylactic acid. Other set of tests is conducted on mold that is structurally same, but made with 3D printing process in a silicate plaster powder material. Material for the casting is zink alloy tagged ZnAl$_4$Cu$_3$ (Table 1) with guaranteed chemical composition.

Table 1 **Composition ZnAl$_4$Cu$_3$ / Wt. %**

%	Al	Cu	Mg	Pb	Cd	Sn	Fe	Ni	Si	Zn
min	3,8	2,7	0,035	-	-	-	-	-	-	oth.
max	4,2	3,3	0,06	0,003	0,003	0,001	0,020	0,001	0,02	oth.

The melting is carried out at the temperature of 420 °C. ZnAl$_4$Cu$_3$ alloy is cast in mold at a temperature of 400 °C. After the completion of the pre-testing mold is modified for further tests.

PRELIMINARY TESTING

In the first preliminary testing, the mold made by Fused Deposition Modeling. As mold cavity model, Archimedean spiral was used as standard test for castability. Height of the mold, altogether with the upper and lower part, is 30 mm. The Archimedean spiral has a diameter of 35 mm and the height of 5 mm. A key item in production of this mold is the inlet system. It is an alloy reservoir that maintains the inlet system during casting full, i.e. preventing air and gas intake. The volume of the inlet cup is determined by the following equation (1):

$$V_c = k\frac{m}{t\rho} \quad (1)$$

Where: V_c - cup volume / dm^3, k - coefficient that depends on the mass of the alloy in the mold (k = 1,5 – 2,0 for a funnel-shaped cup, and k = 3 - 8 for a cupped inlet cup), m - mass of the alloy in the mold / kg. Dietert formula (2):

$$t = 1{,}4\sqrt{m} + 0{,}7 \cdot \delta \cdot \sqrt{m} \tag{2}$$

Where: t-molding time / s, δ – the wall thickness of mold / mm. Coefficient k is 1,5. The rule is that there is a ratio of 1,5 to 2 for the funnel-shaped cup, so the minimum value is taken given the minimum amount of alloy. The data obtained from software tool CATIA are: m = 0,019 kg and δ = 3 mm. Then, according to the formula (2) the casting time t is calculated:

$$t = 1{,}4 \cdot \sqrt{0{,}019} + 0{,}7 \cdot 3 \cdot \sqrt{0{,}019} = 0{,}48 \text{ s} \tag{3}$$

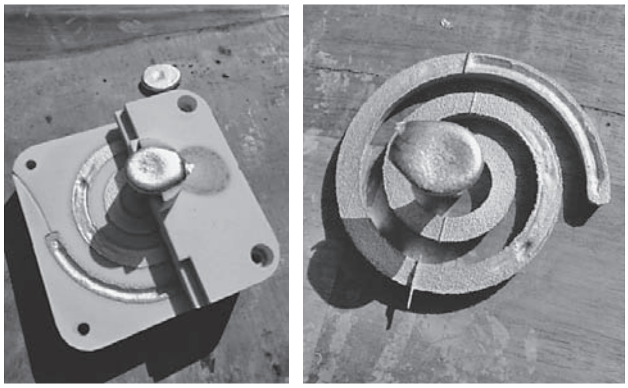
The density of the ZnAl4Cu$_3$ alloy is ρ = 6,8 kg/dm^3. Now all the parameters are incorporated into the equation (1) to calculate the volume of the inlet cup:

$$V_c = 1{,}5 \cdot \frac{0{,}019}{0{,}48 \cdot 6{,}8} = 0{,}00873 \, \text{dm}^3 \tag{4}$$

Upon determining the budget, a mold has been produced in 3DPROFIMAKER. The inner side of the mold has lattice structure for reducing material consumption. The alloy was melt at a temperature of 420 °C. The temperature of alloy casting was controlled at 400 °C. The first casting has failed because of modifications on the inlet system; i.e. mold was destructed. After removing the inlet system, mold occupancy was around 50 %. The comparison is made with the wax model created prior to casting. For the second pre-testing a mold made by 3D printing process was used. The exact composition of the silicate plaster powder material remains unknown due to trade secret owned by 3D Systems. Preheating of the mold to the temperature of T_P = 75 °C was conducted before casting of the alloy in the mold because of the part of the binders from which the layers of the mold are made out of. The mold was filled completely. In some parts, due to the gases that formed during the casting of the alloy and evaporation of binders due to the high temperature at the initial stage of the casting, some irregularities on Archimedean spiral appeared. The inlet system was too small, and thus contained a small portion of alloy that could resist the evaporation of gas in order to get out. The mold was supposed to have a channel at the end of the Archimedean spiral for hot gases to exit and thus not damaging the filling of the mold.

EXPERIMENTAL IN MODIFICAT MOLD

At the end of the Archimedean spiral, a vent for the release of gases during casting was created. During the first casting of the alloy, the mold was over-heated at T_P = 87 °C due to the reduction of humidity inside the mold cavity. After casting, the mold is left in the temperature of 22 °C for 12 minutes to cool down and for the alloy to harden. (Figure 1a).



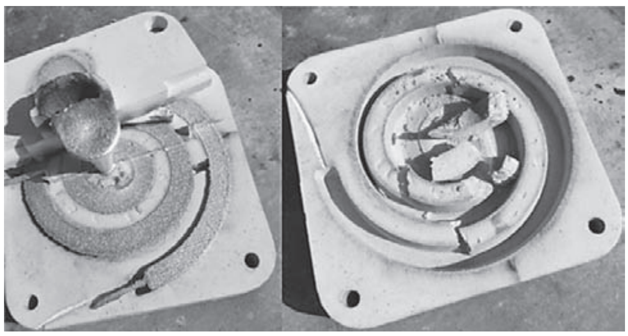
a) b)

Figure 1 Casting after the first casting
a) Opening the mold, b) Casting

There was visible shrinkage porosity around Archimedean spiral after the first casting (Figure 1b). After the assembly, the mold is left for 15 minutes at the casting furnace as in the first casting. The temperature of the mold before the casting was 80 °C, which is 5 °C more in regards to the first casting. Despite previously sanded side edges of the Archimedean spiral, the casting is still demolding with difficulty. After removing the upper part of the mold, auxiliary tools were used to hold the bottom part of the mold, which was softer in comparison to after the first casting. Casting has completely filled the mold and no evidence of shrinkage porosity is detected. The mold is preheated to a temperature of T_P = 90 °C when the casting commences.

After the third cycle, the casting has filled the entire mold and there was no shrinkage porosity detected. (Figure 2a) While demolding, the mold collapsed. (Figure 2b). New mold has been created. The mold should be preheated to the temperature of T_P = 95° C. To prevent further softening of the mold during casting and high temperatures, we primed it with a coat of Zirconium dioxide (ZrO_2) that prevents heat from penetrating into the mold. After assembly the mold is first left at T_P = 75 °C.

After dismantling the mold, it is noted that the alloy has not filled the mold properly and that there is visible shrinkage porosity. (Figure 3) Alloy had completely filled the mold.



a) b)

Figure 2 Casting after the third casting
a) Opening the mold, b) Casting

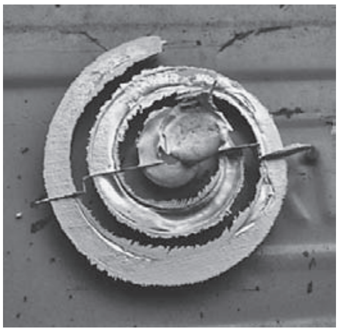


Figure 3 Casting after the first casting with ZrO_2 coating

RESULTS AND DISCUSSION

After each casting in the modified mold the measured by mass of the casting was compared to the ideal mass, which is calculated by the software Catia. The ideal weight of a casting is 0,168 kg. (Table 2)

Table 2 **Mold without protective coating**

Cast No.	Temperature of alloy T_L / °C	Preheating temperature T_P / °C	Casting mass m / kg
1.	480	75	0,148
2.	470	80	0,149
3.	465	90	0,152
4.	450	90	0,159
5.	440	95	0,168

The first casting in the cycle gives the worst results (t = 15 min, T_P = 75 °C). This is normal due to the insufficient heat of the mold and excessive temperature difference between alloy and mold. The mold collapsed after only two castings and it was not possible to examine pre-heating of the mold. The reason for such phenomenon is the evaporation of binders within the mold and the mold becomes unusable for further castings. New mold was created and three castings were performed. In the final casting, the full occupancy of the mold was achieved and the mass of the casting was m = 0,168 kg. Due to the destruction of the mold after 2 or 3 cycles of casting, surface protection through Zirconium dioxide coating (ZrO_2) was used. Figure 4 shows the surface diagram for the mold without Zirconium coating. Where is T_L-temperature of alloy, T_P - preheating temperature of mold and m - mass of casting. The temperature of alloy was reduced to 40 °C, and the mass of the mold is increased to the maximum casting mass of 0,168 kg.

Table 3 shows the number of cycles of six castings with variables: time of heating the mold and the heating temperature to the ideal mass in casting. The mold remained whole even after 6 cycles of casting. (Table 3)

With the use of Zirconium dioxide coating, the number of repetitions increased, as well as the strength and quality of the castings. The first casting was the worst. Due to the Zirconium coating, higher temperature of pre-heating is necessary. After the sixth casting, small flaws were detected in the bottom of the root of the Archimedean spiral. However, the mold hardness remained stable. Figure 5 shows the surface diagram of the mold with Zirconium dioxide coating (ZrO_2).

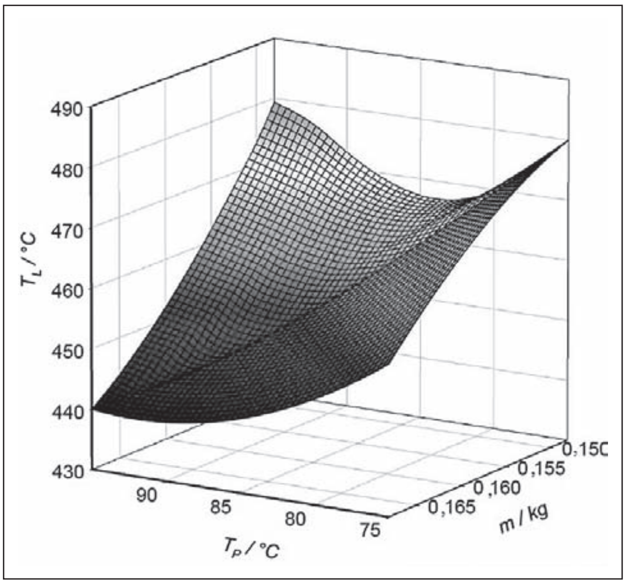


Figure 4 Dependency diagram T_L-T_P-m

Table 3 **Mold with Zirconium dioxide coating**

Cast No.	Temperature of alloy T_L / °C	Preheating temperature T_P / °C	Casting mass m / kg
1.	480	75	0,120
2.	460	90	0,147
3.	440	95	0,157
4.	420	95	0,163
5.	400	95	0,168

Zirconium coating has enabled a significant reduction in the alloy temperature and extended the longevity of the mold to the cycle of 10 castings. The temperature of alloy was reduced to T_P = 80 °C, and the occupancy of the mold is increased to the maximum casting mass of 0,168 kg.

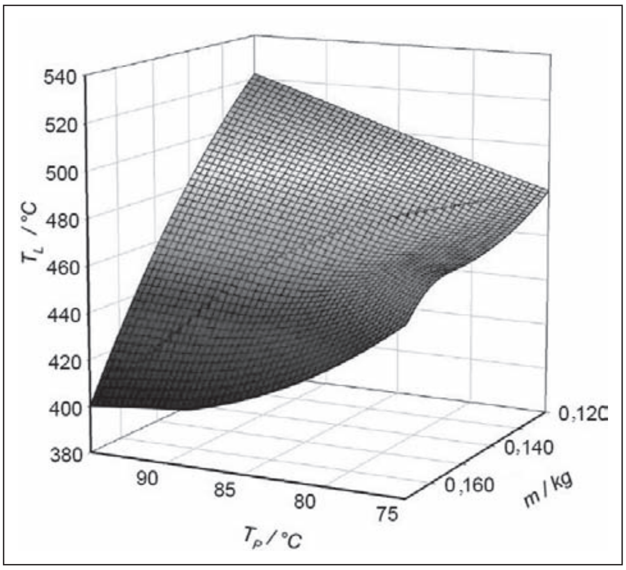


Figure 5 Dependency diagram T_L-T_P-m with ZrO_2

CONCLUSIONS

In relation to previous molding processes, using this method the molds are produced much faster and price is reasonable compared to the previous methods regarding the time it takes to produce a mold. From obtained results it is clearly seen that printed mold must be protected with thermal coating because liquid adhesive of powder otherwise evaporates during casting and creates additional moisture in the mold, as it was noted. Thus the evaporation of liquid adhesive distorts the structure, and therefore the dimensions of the casting after casting. Printed mold must be protected with thermal coating because liquid adhesive of powder otherwise evaporates during casting and creates additional moisture in the mold, as it was noted. Thus the evaporation of liquid adhesive distorts the structure, and therefore the dimensions of the casting after casting.

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Note: The responsible translator for English language is prof. Šerbo Hušidić, permanent court interpreter for English